PREDICTING EARTH ORIENTATION

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ABSTRACT. Predictions of Earth orientation parameters are affected by the accuracy of the input data, the quality of the statistical models, and the delay between the last observed data and the date of the first prediction. The accuracy of the prediction of polar motion is adequate to meet most user needs, but the prediction of UT1-UTC is more difficult. Extended forecasts of polar motion and the rotational time can also be made with useful accuracies.

1. INTRODUCTION

To relate coordinate reference frames operationally it is often necessary to have predictions of the Earth orientation parameters (x, y, UTI-UTC). These requirements arise for navigation purposes as well as in the need for high-precision observational predictions and for high-speed reduction of observational data. The U.S. Naval Observatory provides predictions weekly in the form of printed bulletins (National Earth Orientation Service Earth Orientation Bulletin) as well as in computer-accessible files. These forecasts are made for the forty days following the date of the prediction. The accuracy of values decays with time as might be expected. The purpose of this paper is to review the important factors to be considered in improving the accuracy of the predictions as well as our current capabilities.

2. FACTORS AFFECTING PREDICTION ACCURACY

Three principal factors affect the accuracy with which prediction of x, y, and UT1-UTC can be made. These are (1) accuracy of the observational data used to produce the predictions, (2) the quality of the prediction algorithm, and (3) the delay between the instant of observation and the time when these data are reduced and/or received at the U.S. Naval Observatory. Each of these factors affects the quality of the forecasts.

A. K. Babcock and G. A. Wilkins (eds.), The Earth's Rotation and Reference Frames for Geodesy and Geodynamics, 275–280.

2.2. Quality of Prediction Model

The second consideration in accurate prediction of Earth orientation is the nature of the mathematical model used to make the predictions. Because variations in polar motion and UT1-UTC are quite different, two different models are employed to make the predictions.

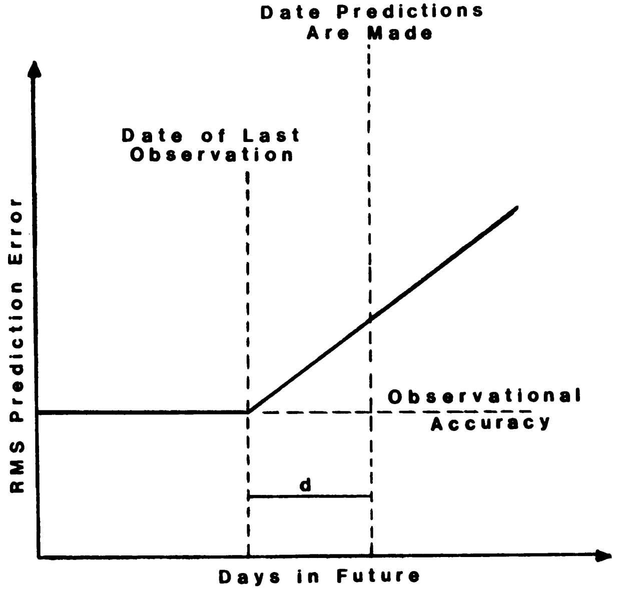

Figure 1. Schematic representation of factors affecting prediction accuracy.

2.2.1. Prediction of Polar Motion

Polar motion is dominated by two components, the Chandler motion and the forced annual motion. Any other components, if they exist, are much less important. Thus the algorithm used to predict polar motion is based on representing these two motions. The polar coordinates, x and y, are fit to a mathematical model composed of an elliptical annual motion, a circular Chandler motion (435-day period) and a center of the polar motion. Two years of data are used to determine the unknown constants needed to describe the motion (two describing the circular motion, four describing the annual motion, and two describing the center of the pole path).

Two years of data were found empirically to be adequate to provide a good description of the polar motion and yet be responsive to changes in the motion which might occur on a relatively short time scale. Other models, such as one employing a variable Chandler frequency, were found to be inadequate.

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2.1. Accuracy of Observational Data

The data upon which the predictions are based are the Earth orientation parameters produced each week at the U.S. Naval Observatory (USNO). This information results from the solution which combines the data obtained from a number of sources. These include very long baseline interferometery (VLBI) data from Project IRIS, satellite laser data from the University of Texas Center for Space Research, Doppler polar motion from Defense Mapping Agency, Connected - Element Interferometer data, from Green Bank, West Virginia and optical astrometric data from USNO.

Not all of these sources may be used to produce the entire input data set for the prediction algorithim. This is because some sources require a longer time than others to reach their final status and thus are not available for input to the combination solution at the time when the predictions must be made. For example, the VLBI data, currently requiring about two months from the time of observation until they are in final form, can not be used in the production of the most recent part of the input data set. They are used up through the last available date, but following that date the combination solution must be formed without the VLBI contribution. The same situation prevails for any of the sources which, for some reason, are temporarily unavailable for the CORE solution.

As a result, the most recent data (thirty days previous to prediction date) on which the predictions are based are less accurate than the older data which are formed using the complete set of contributed data. Table 1 shows the estimated accuracies of the Earth orientation parameters in each of these two subsets.

Table 1. Accuracies of Earth orientation parameters for two different subsets of contributed data. Full-Rate refers to the data produced from the entire contributed set. Quick-Look refers to the recent data produced with limited data contributions. Usually the latter data set covers the time period of the most recent thirty days.

	Full-Rate	Quick-Look
x	$\pm 0\overset{''}{.}0018$	$\pm 0\overset{''}{.}0023$
y	$\pm 0\overset{''}{.}0010$	$\pm 0\overset{''}{.}0016$
UT1-UTC	$\pm 0\overset{s}{.}00010$	$\pm 0\overset{s}{.}00022$

As would be expected, the most accurate predictions result from the most accurate input data. Figure 1 illustrates the effect of input data accuracy on the prediction accuracy.

2.2.2. Prediction of Universal Time

The model to be used for the prediction of Universal Time is not as obvious as that for polar motion. A seasonal variation traditionally modeled by annual and semi-annual sinusoids is well known. The variation in rotational speed caused by zonal tides is also predictable using a theoretical model. The model must, therefore, incorporate these known variations. The largest variations in UT1-UTC are, however, not represented by analytical models. Experimentation with numerous possibilities has shown that an autoregressive filter operating on the observed values of UT1-UTC for the thirty days preceding the day on which the predictions are made is the optimum algorithm to be used.

Thirty days of observed UT1-UTC are treated by removing the known seasonal and zonal tidal effects. The BIH seasonal variation was found to be adequate to represent the seasonal terms. Alternate expressions may be more representative for some periods of time, but no significant general improvement was found by using such expressions. The zonal tidal representation given in the Project MERIT Standards is also used. Adjustment for leap seconds may also be necessary in order to obtain a continuous input data set. Predictions for the i^{th} day in the future are then formed using an expression

$$\mathrm{UT1\text{-}UTC}\ (T + i) = \sum_{j=1}^{30} a_{ij}\ \mathrm{UT1\text{-}UTC}\ (T - j),$$

where T represents the date on which the prediction is made and the a_{ij} are empirical coefficients determined from past observations. Finally, the seasonal and zonal tidal effects are added to obtain the values of the predictions. Adjustments may also be made for future leap seconds at this point. Other models were tested experimentally but this procedure was found to provide the best agreement between predictions and actual values of UT1-UTC for extended periods of time. The agreement was measured by the rms of the differences between the predictions and actual values.

2.3. Processing Delay

Perhaps the most critical of all items to be considered in making predictions of Earth orientation parameters is the delay in time between the last derived estimates of x,y and UT1-UTC and the day on which the predictions must be formed. Delays in receiving observed data not only reduce the quality of the input data but also produce an interval in time, d, between the last actual value and the first prediction required. Thus the predicted value for the first date required will in fact be a prediction for an epoch T+d. Figure 1 also shows this effect.

3. ACCURACY OF PREDICTIONS

The accuracy of the predictions can be tested by comparing the predictions of the Earth orientation parameters with the final values determined some weeks later. Table 2 shows the accuracy of the predictions derived in this manner.

Table 2. Accuracies of the predictions of the Earth orientation parameters.

Days Ahead:	10	20	30	40
Pole Position	$0\overset{''}{.}010$	$0\overset{''}{.}010$	$0\overset{''}{.}011$	$0\overset{''}{.}011$
UT1-UTC	$0\overset{s}{.}0033$	$0\overset{s}{.}0049$	$0\overset{s}{.}0068$	$0\overset{s}{.}0090$

4. PREDICTIONS FOR EXTENDED PERIODS

Requests also arise for the prediction of Earth orientation parameters for periods greater than forty days in the future. For this purpose analytical extrapolation functions can be provided. However, for epochs greater than about 150 days in the future, it appears that more accurate predictions of UT1-UTC may be obtained if we use more of the historical data as input to an autoregressive model which is different from the one used to form the predictions of the UT1-UTC for periods less than 150 days. In formulating this algorithm it was found that extended predictions were improved if up to fifty years of past estimates of TDT-UT were used as input. As was the case for the short-term predictions the data were treated by removing seasonal, tidal and leap second effects. An autoregressive predictor is applied and seasonal, tidal and leap seconds are restored. The procedure used to predict polar motion is not improved by anything more than what is described above. Table 3 lists the accuracies of the long-term predictions derived in this manner.

Table 3. Accuracies of the predictions of the Earth orientation parameters.

Years Ahead:	0.5	1.0	1.5	2.0
Pole Position	$0\overset{''}{.}02$	$0\overset{''}{.}04$	$0\overset{''}{.}07$	$0\overset{''}{.}09$
UT1-UTC	$0\overset{s}{.}045$	$0\overset{s}{.}12$	$0\overset{s}{.}20$	$0\overset{s}{.}28$

5. CONCLUSION

Predictions of Earth orientation parameters are affected by the accuracy of the input data, the quality of the prediction models, and the delay between the last observation and the date on which the predictions must be made. Prediction accuracies are able to meet all user requirements for polar motion but not UT1-UTC. The delay between observations and prediction date is most critical and should be reduced in the future. Extended forecasts of Earth orientation with useful accuracies are also possible.

DISCUSSION

Standish: I would like to know what are the major contributing factors in your prediction model. In particular, what effects do the angular momentum budget and the uncertainties of the nutation model have?

Reply by McCarthy: The model is based on statistical analyses of past observations. At this point predictions of atmospheric angular momentum are not useful in making predictions because of their low accuracy. Uncertainties in nutation theory are too small to affect predictions.

Dickey: You showed a graph displaying the growth of error in polar motion as a function of time. It flattens out after some time. Why?

Reply by McCarthy: Because polar motion is essentially bounded. The longer-term polar motion is predictable at the level shown on the plot.

Dickey: At one point, I believe that the USNO required that the predictions pass through the last data point. Is this still true?

Reply by McCarthy: In polar motion, yes, but in UT1-UTC, no.

Débarbat: In the CORE for quick-look values, CEI has a weight which is two times the weight of the optical astrometry for prediction of UT. What is the influence on the quality of the prediction when you have no results in UT from one or the other of these techniques?

Reply by McCarthy: The quality of the predictions depends on (among other things) the accuracy of the input data. To the extent that the accuracy of the determination of the observed input data is degraded, the prediction quality will be degraded.

Carter: Considering the short period agreement of VLBI and SLR UT1 series, why does the SLR UT1 data receive such low weight in the CORE rapid results?

Reply by McCarthy: The weights are based on statistical analysis of past comparisons and the accuracy with which systematic error models can be derived. The SLR UT1 estimates appear to have improved recently and this will probably be reflected in increasing weight in the solution.

Chao: Is there any particular reason why you use 2 years of data in your polar motion predictions?

Reply by McCarthy: Two years are chosen in order to have sufficient data to determine the parameters describing the annual ellipse and Chandler circle. A longer period is not used so that the model will be responsive to physical changes.

Eubanks: You didn't say much about the method used in the UT1 prediction. Is it the same as in the paper you included in the ESA special publication on *Statistical Methods in Astronomy*?

Reply by McCarthy: No; I believe that the model used in that paper used a longer stretch of past UT1 data. The current model is an autoregressive model in which the UT1 data for each day of the past 30 days contribute to the UT1 prediction.

Fallon: How do you treat the 2-dimensional character of pole position? Why does short-term error in pole level off, while long-term error increases with time?

Reply by McCarthy: (1) A complex solution is made for the pole position. That is, the ellipse and circle are fit to the (x,y) data. (2) Polar motion is essentially bounded and this can be predicted at the level shown. The rotational speed is subject to large variations at low frequencies.